NASA experience and lessons learned in data quality and cal/val for optical missions (with help from the commercial side)

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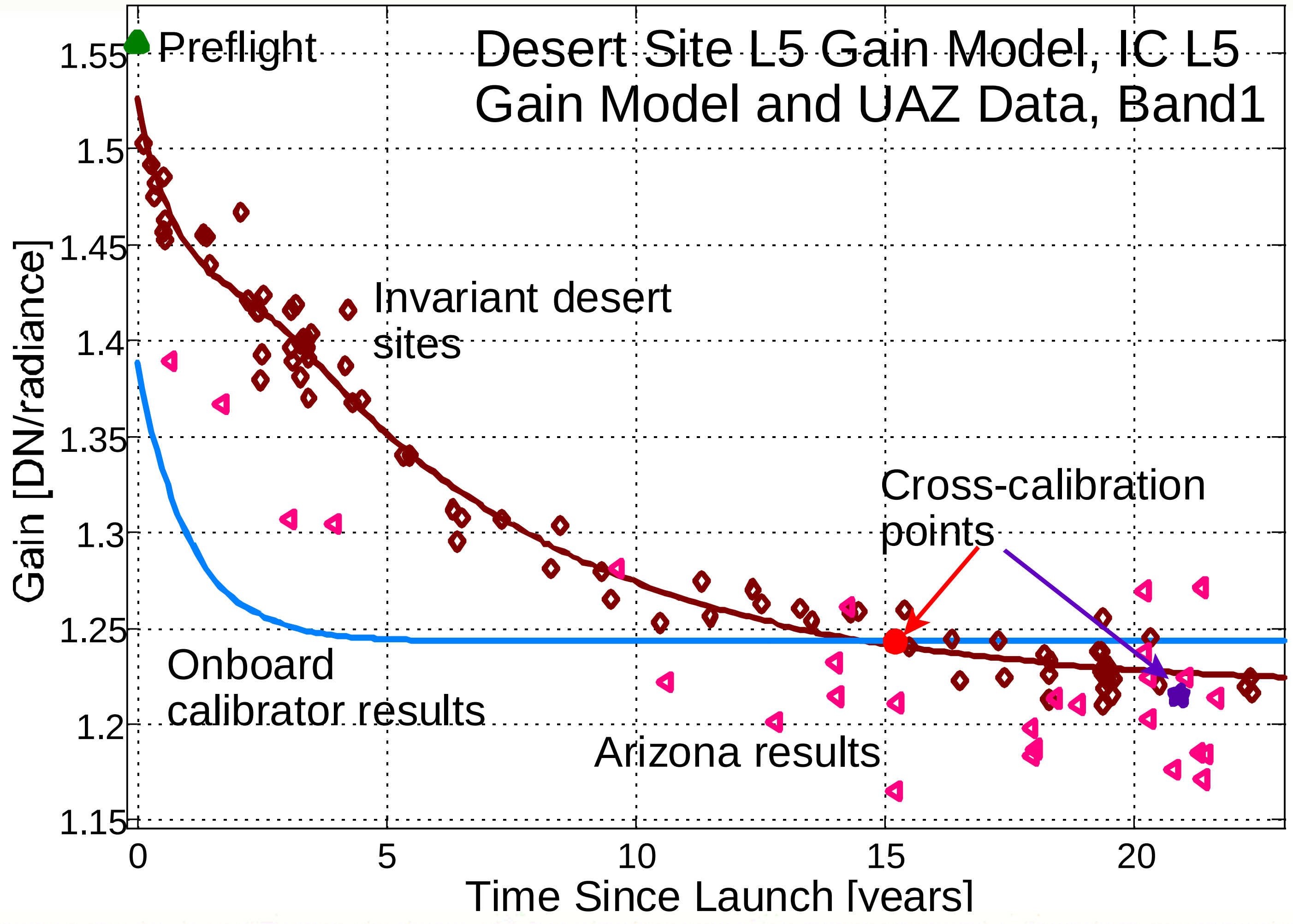
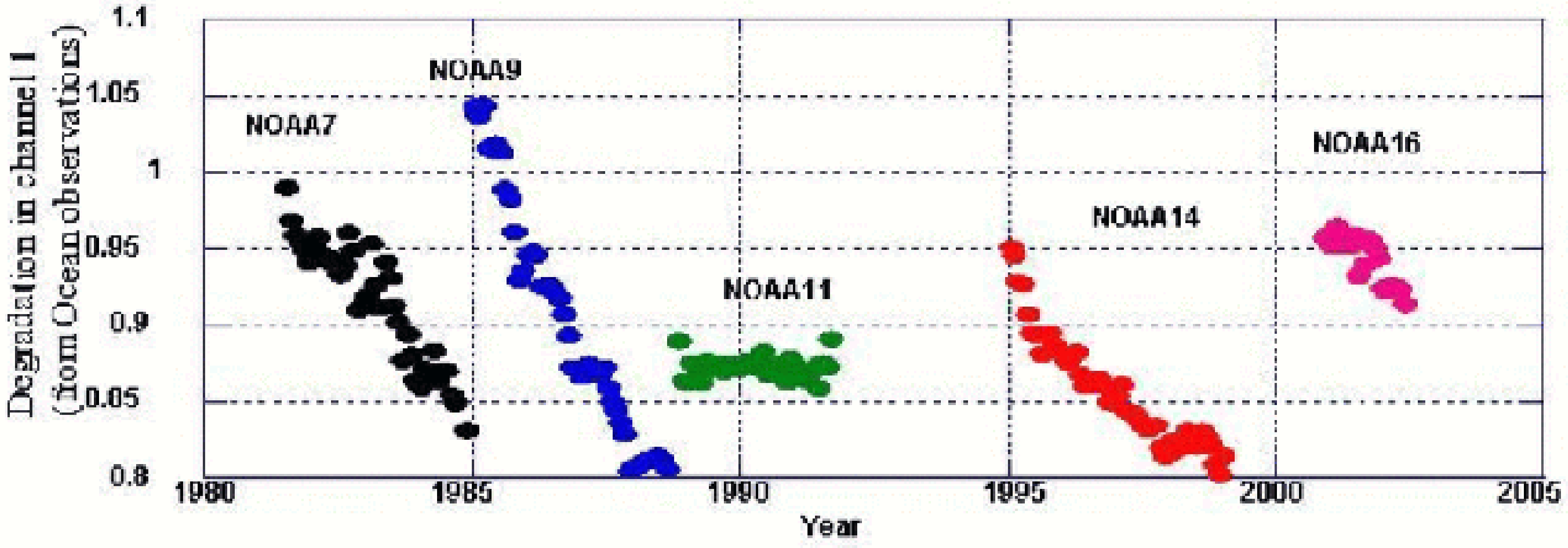
Talk outline is the conclusions

- We start new missions by fighting our last battle
- New missions need calibration results in weeks not decades
- The need for SI-traceability is well understood
- The difference between calibration and characterization is often confused
- Cal/Val community has gone from wondering whether low-cost sensors will work to helping ensure they are fit for purpose
- User community is great at finding striping
- We still confuse the difference between significant and noticeable
- It is not possible to produce a global seamless data product from multiple sensors using current approaches without noticeable artifacts

We start new missions by fighting our last battle

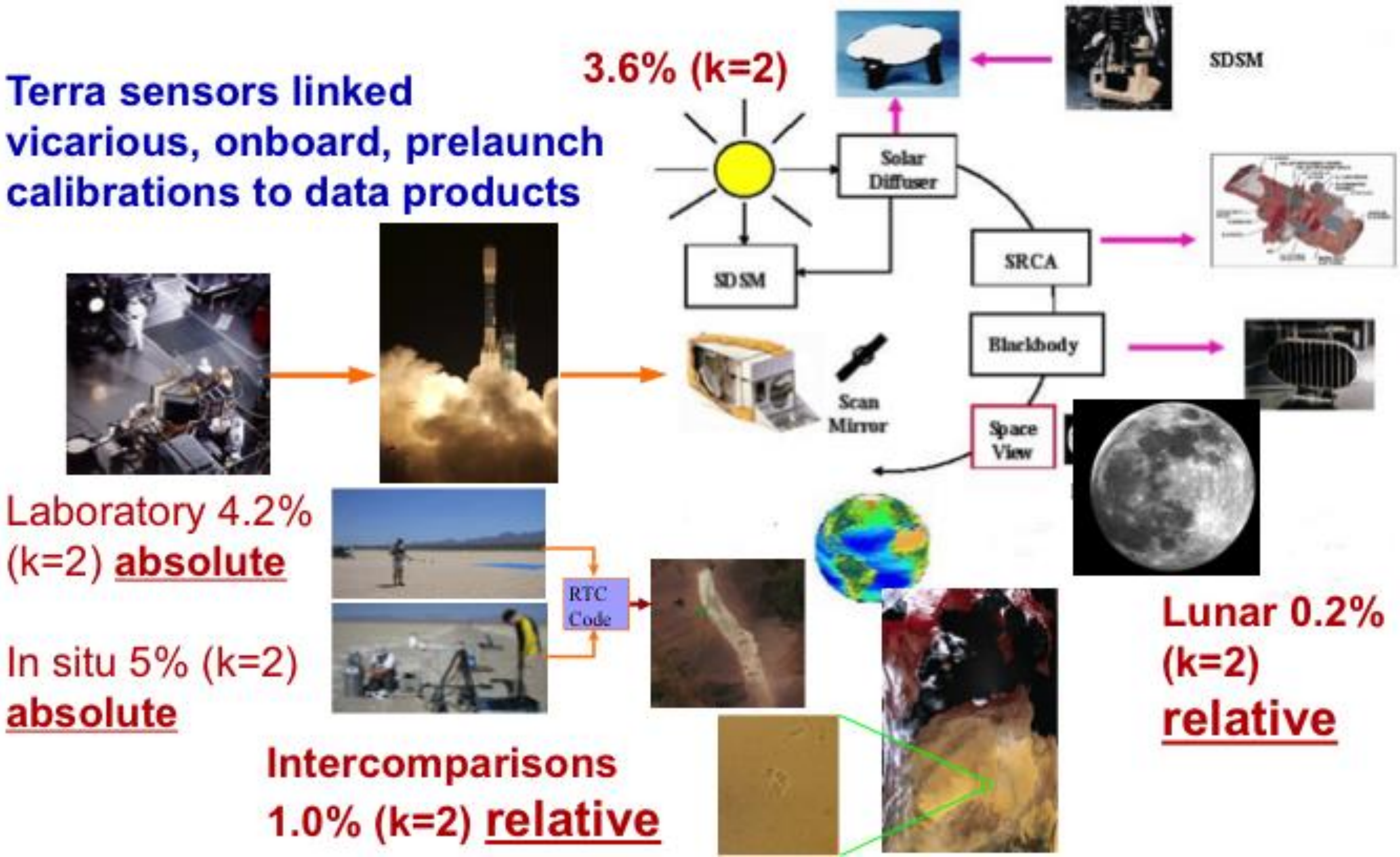
- Landsat-5 Thematic Mapper was a first battle for many of us
  - Preflight calibration did not match early on orbit data
  - Sensor behavior did not match the onboard calibrators
- AVHRR is still providing challenges
  - No onboard calibration
  - Changing sensors and orbits
- Led to emphasis on absolute radiometric calibration and better onboard calibrators
- Showed the importance of vicarious calibration

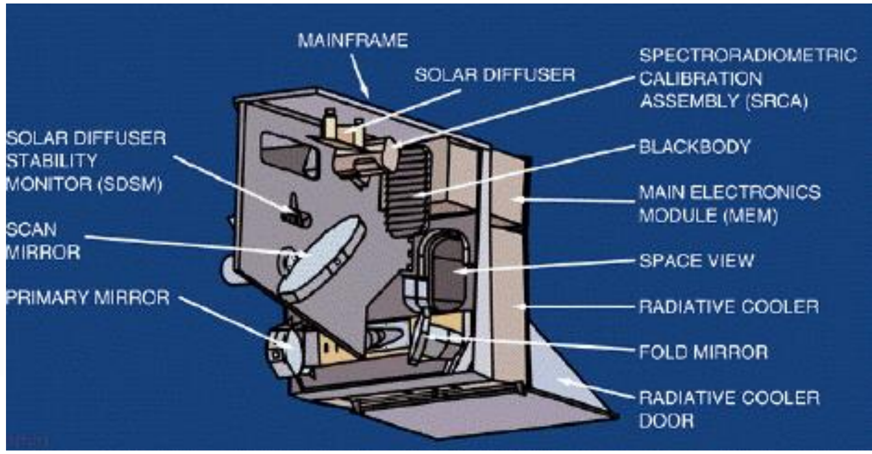


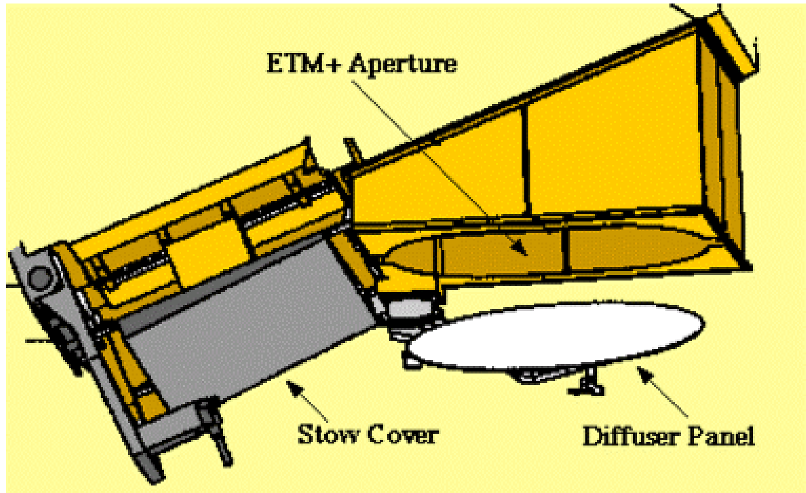


We tend to start new missions by fighting our last battle

The results were the sensors of the 1990s on large platforms and elaborate onboard calibration and multiple vicarious methods



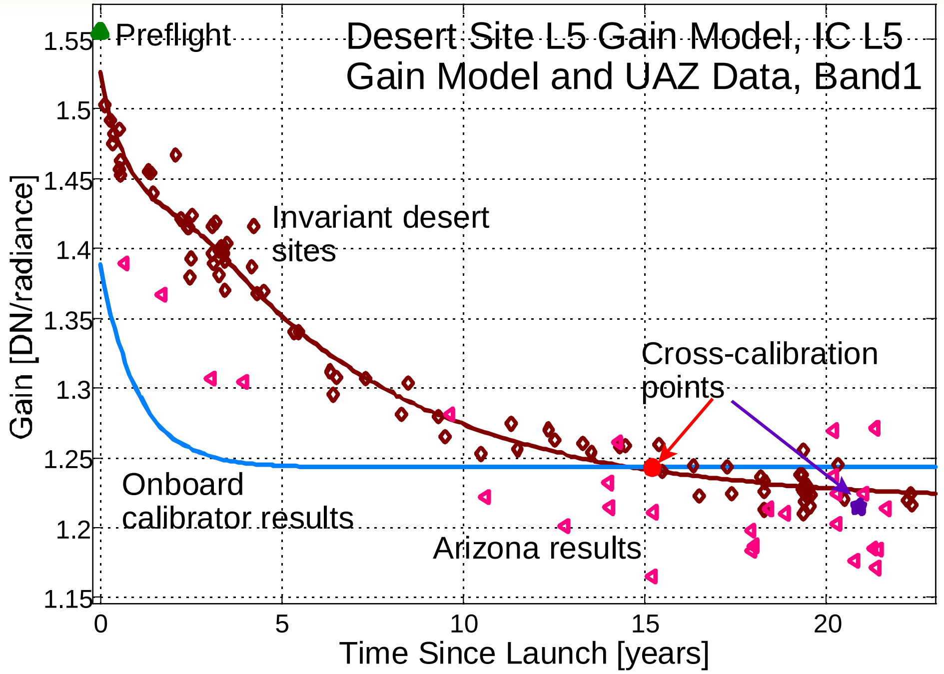


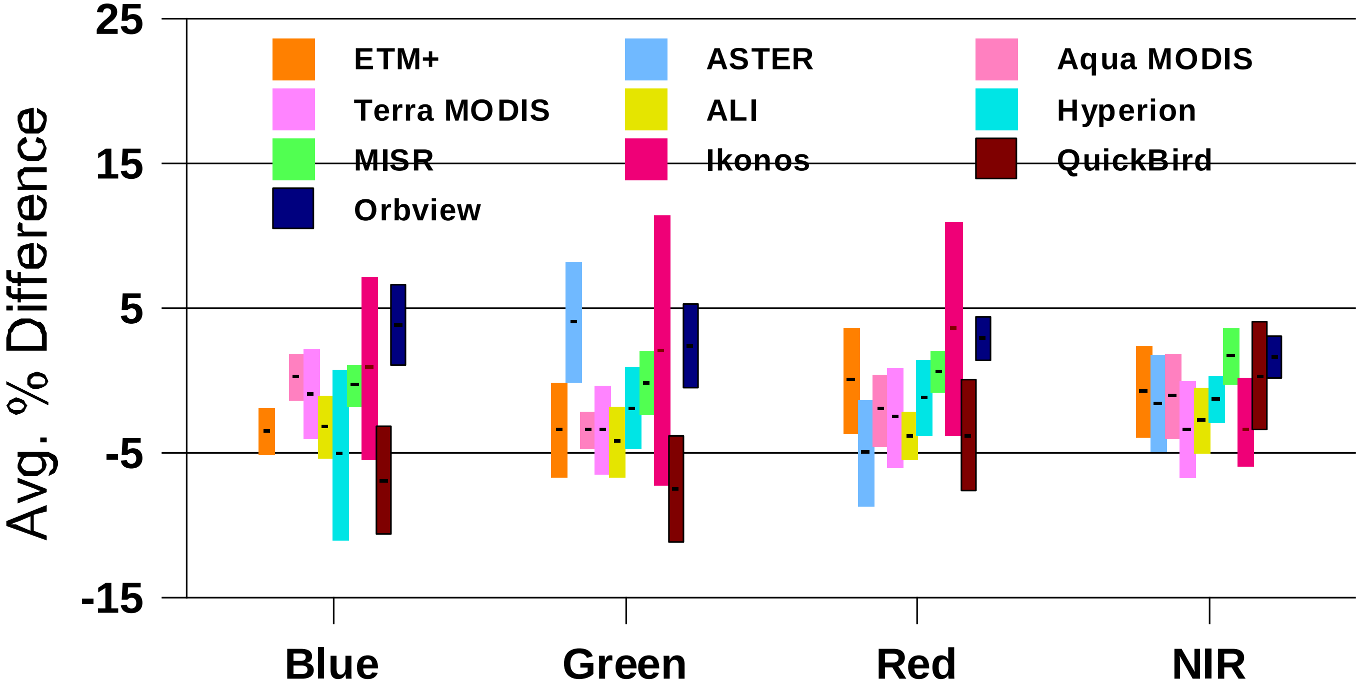


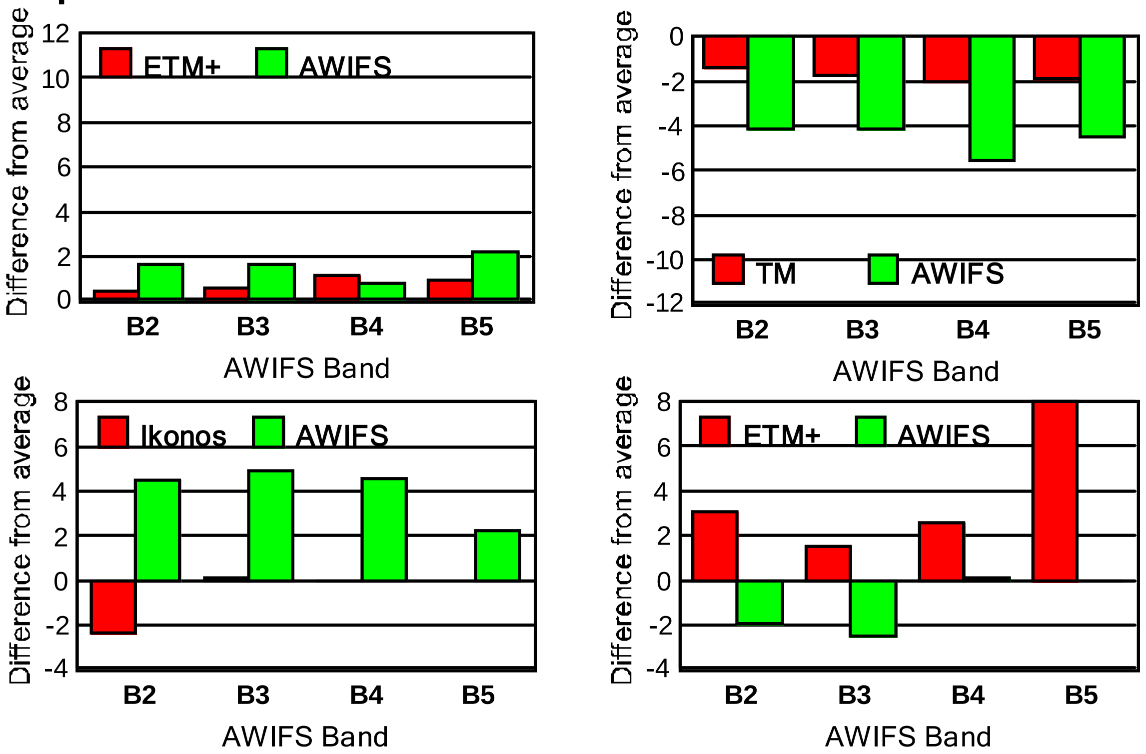
New missions need calibration results in weeks not decades

We always want one more data point

- Took more than 15 years attempting to perfect our understanding of the radiometric trend of TM and then change the official calibration
- Commercial systems need faster evaluation and that helped push development of intercalibration
- Short-term missions need faster evaluation and that helped push the development of new techniques



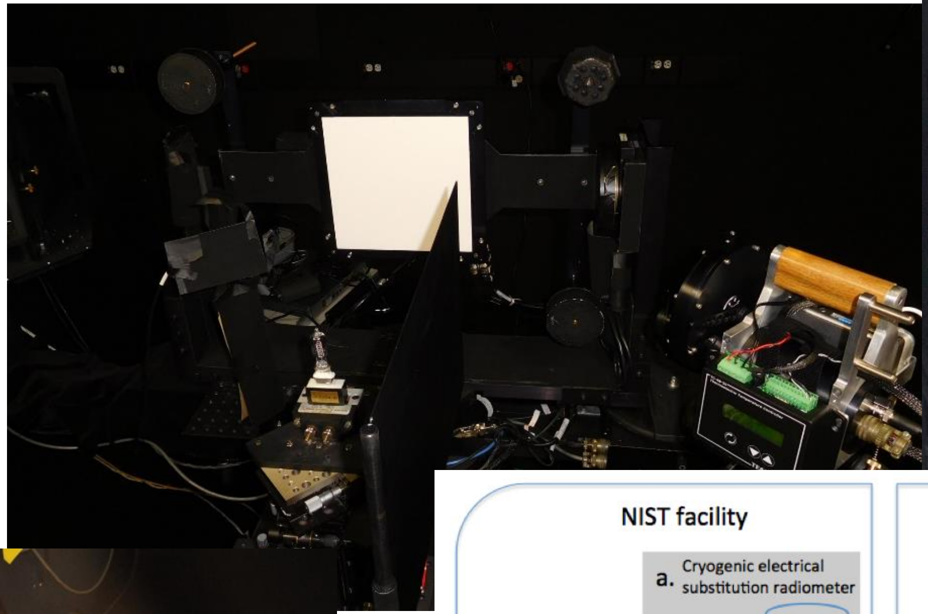


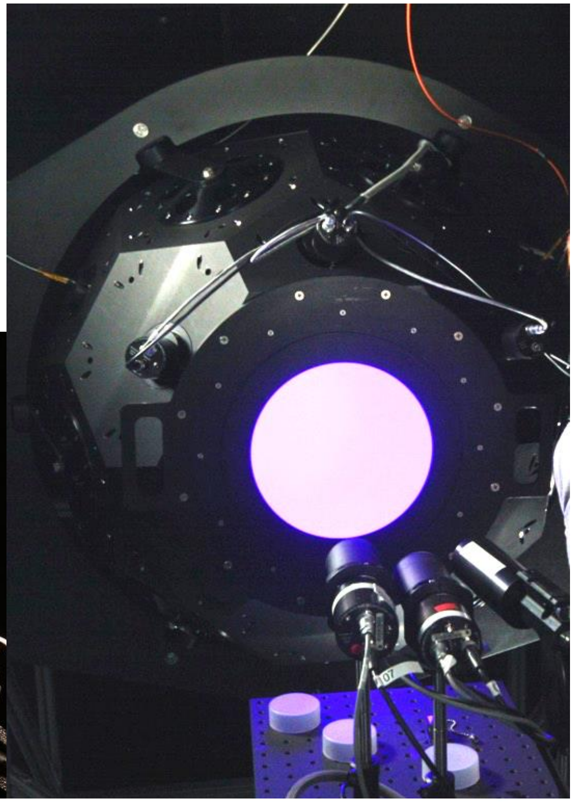


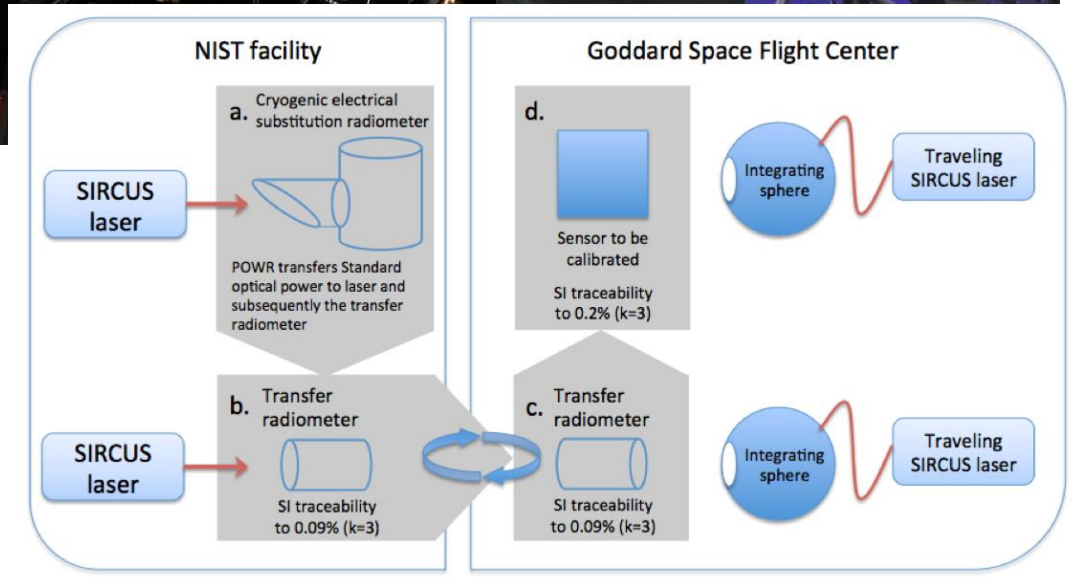
The need for SI-traceability is well understood

SI-Traceability with established uncertainties is the only path to bridging gaps in sensor data records

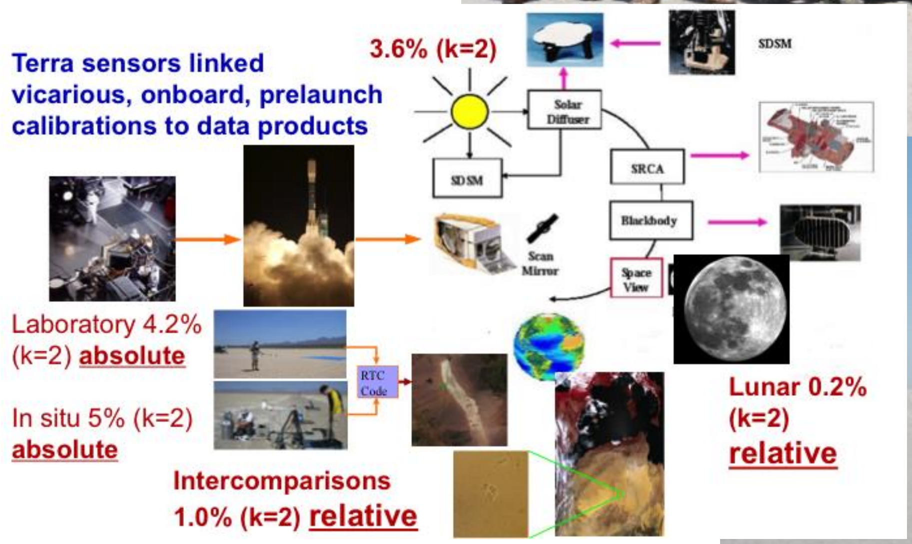
- Provides link between multiple measurement approaches
- Provides link between field and laboratory

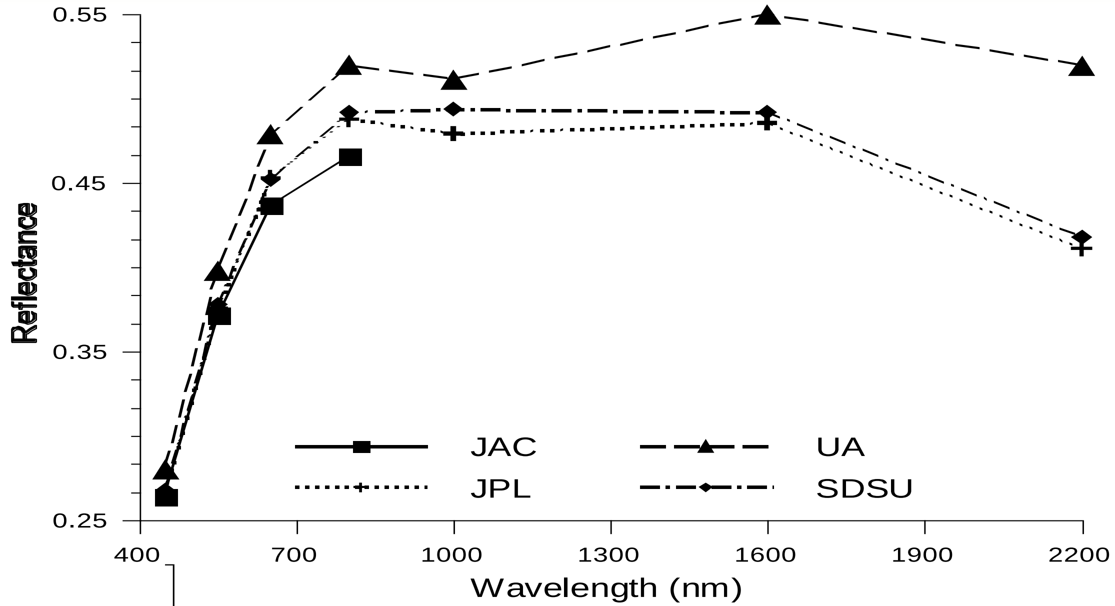


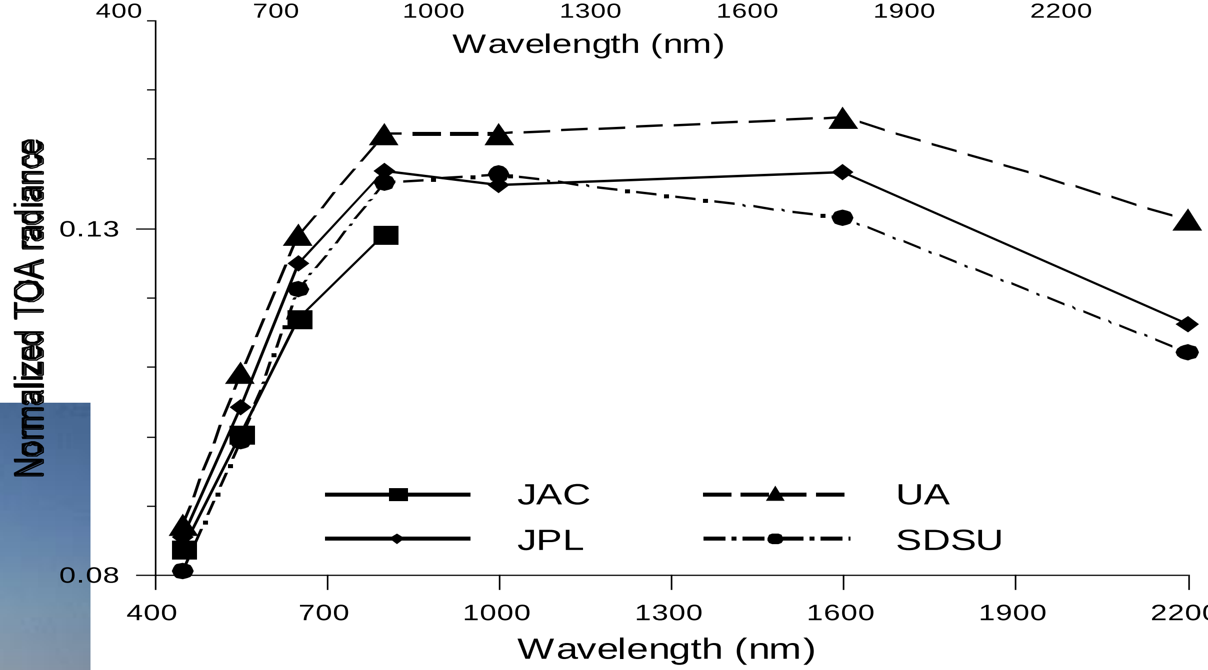




“All for one” approach relies on SI-Traceability







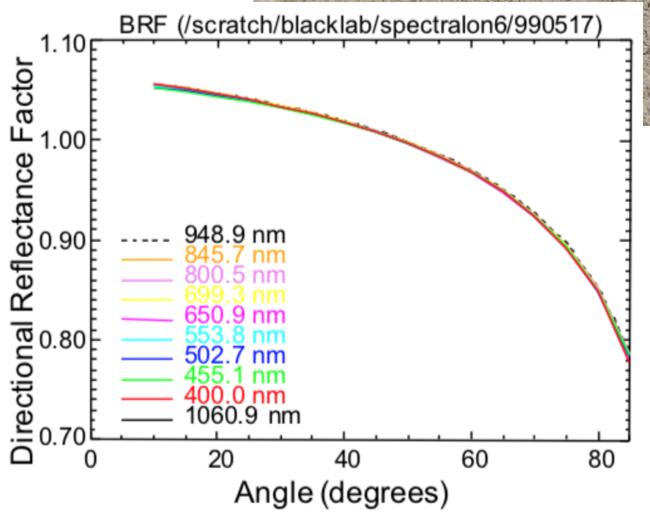
“All for one” is the only feasible path to multi-sensor science

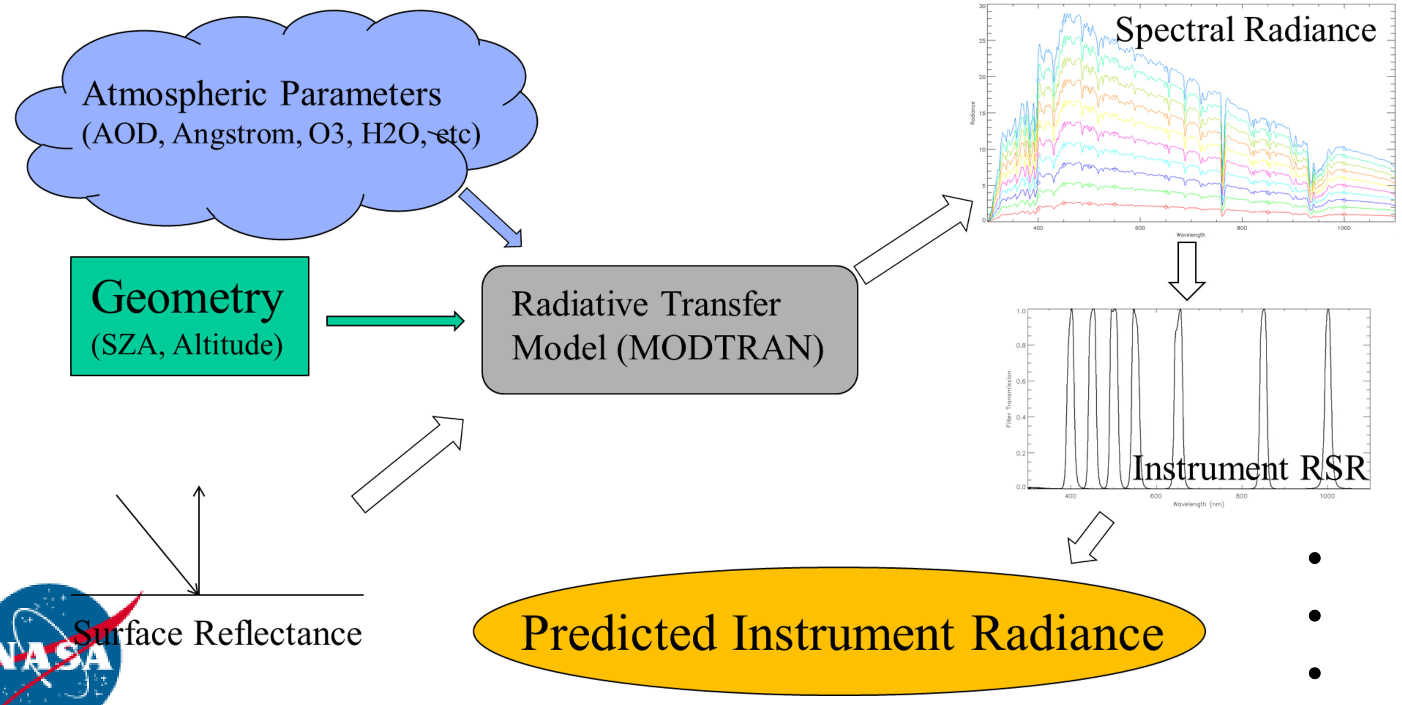
SI-Traceability and multiple processing methods

- Reflectance-based retrieval of reflectance

$$Reflectance = \frac{Signal(Ground)}{Signal\ (Panel)} * Panel\ BRF$$

- Straightforward
- Instrument stability more important than absolute calibration
- Lower uncertainties



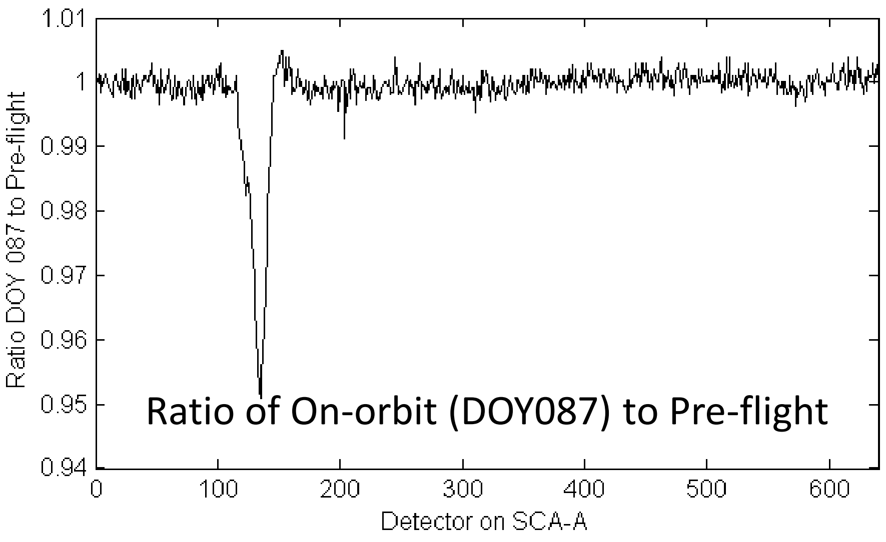


- Radiance-based retrieval of reflectance combines measured ground radiance with predicted radiance given known atmospheric and geometric conditions
  - No Reference Panel
  - Simplified measurement
  - SI traceability has clearer path

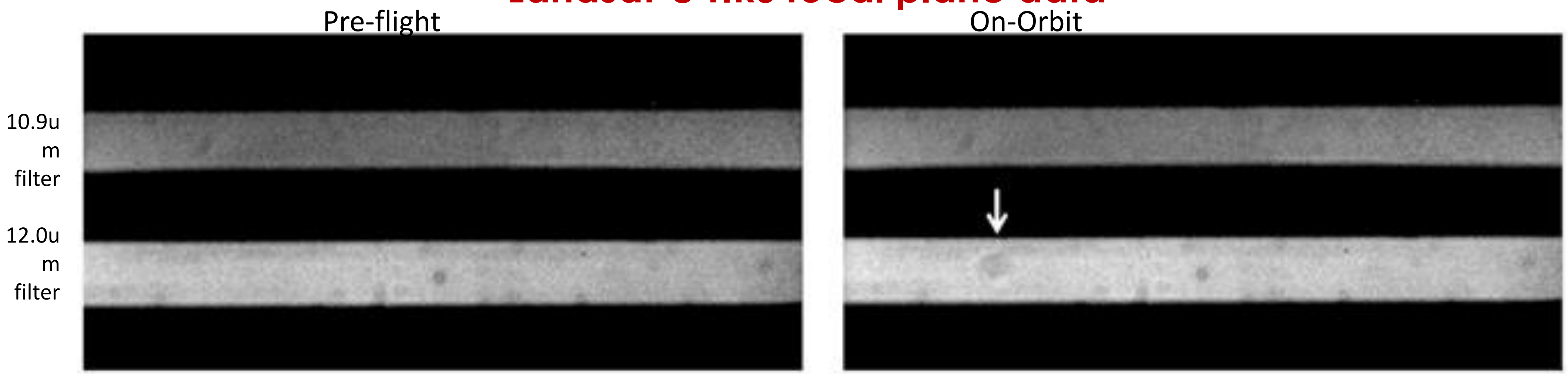
There is a difference between calibration and characterization

Relative calibration and sensor characterization are still critical to ensure post-launch data quality

- Push towards reducing preflight and onboard calibration to reduce cost and schedule
- Comprehensive characterization is needed to allow understanding of on-orbit sensor behavior and calibration
  - There are cost-effective and schedule-friendly means to comprehensive characterization
  - Make better use of component-level testing and instrument models



Landsat-8 TIRS focal plane data

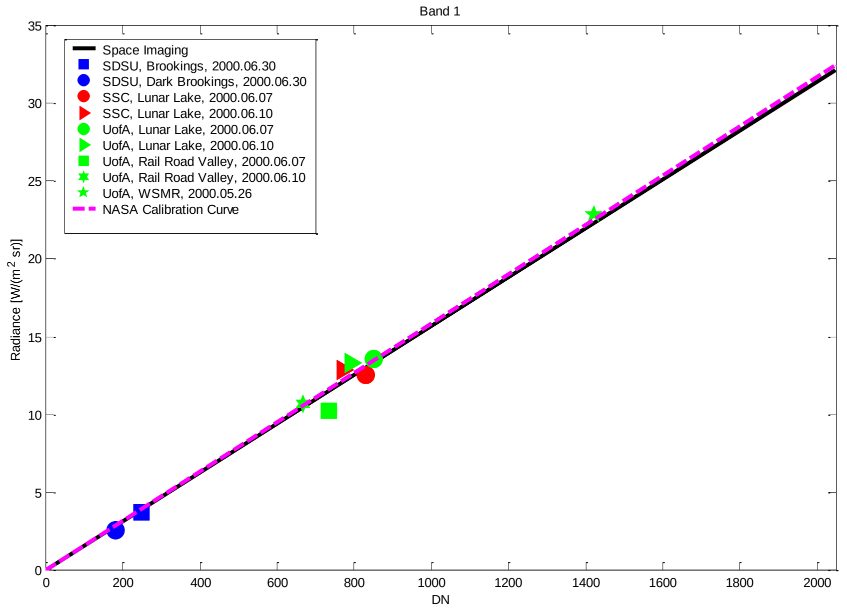


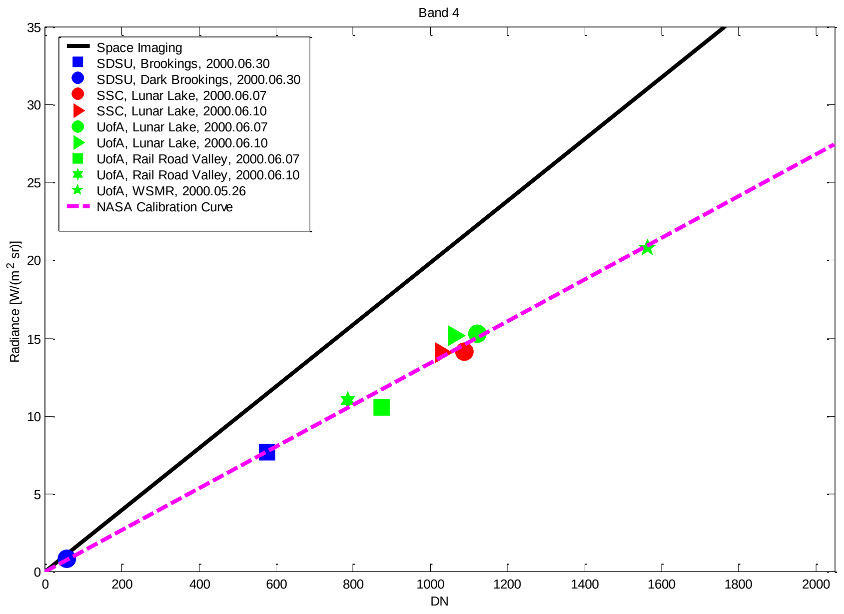
Would low cost sensors work?

Cal/Val community has gone from wondering whether low-cost sensors will work to helping ensure they are fit for purpose

- Users in the 90s were not sure that low cost and/or commercial sensors would provide usable imagery
- Joint Agency Commercial Image Evaluation (JACIE) Team was the US Government's response to evaluate this
- JACIE quickly moved to whether the systems were calibratable
- Evaluation of sensor calibration was next

Initial Ikonos blue and NIR band calibration comparisons with three independent JACIE-funded teams



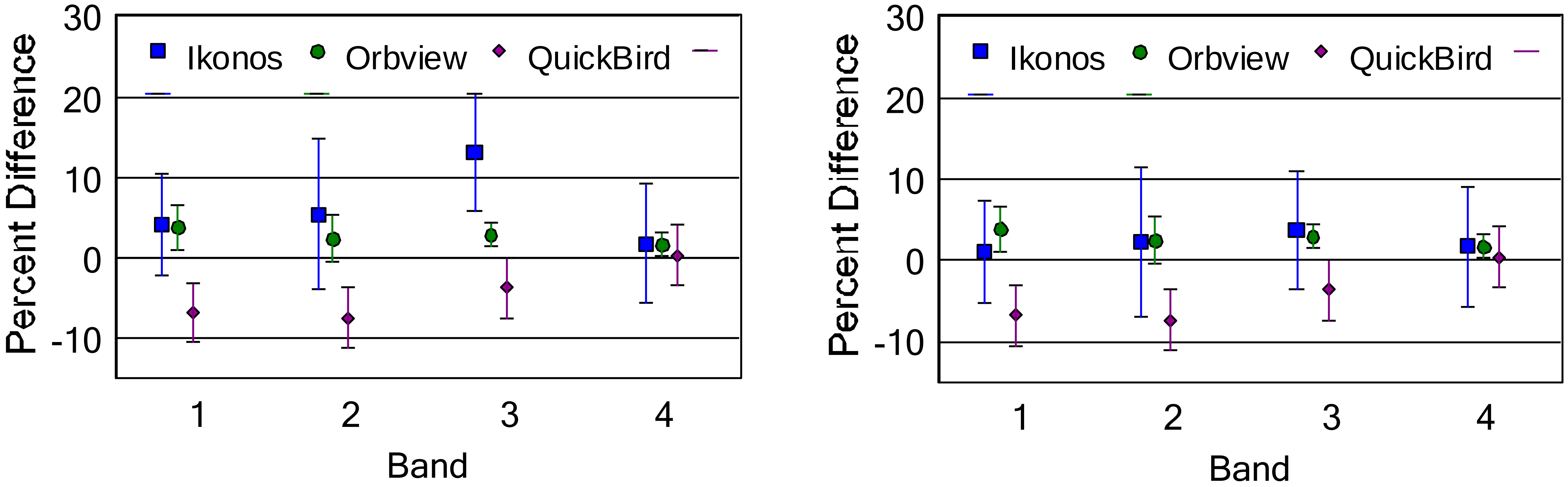


Space Imaging modified its sensor calibration to take into account the JACIE results

Key lesson learned from JACIE was communication

- Moved towards improving communication between the users and providers
  - Understand subtle processing differences
  - SI-traceability paths
  - History of calibration coefficient determination
- Still working to improve on length of time to obtain results

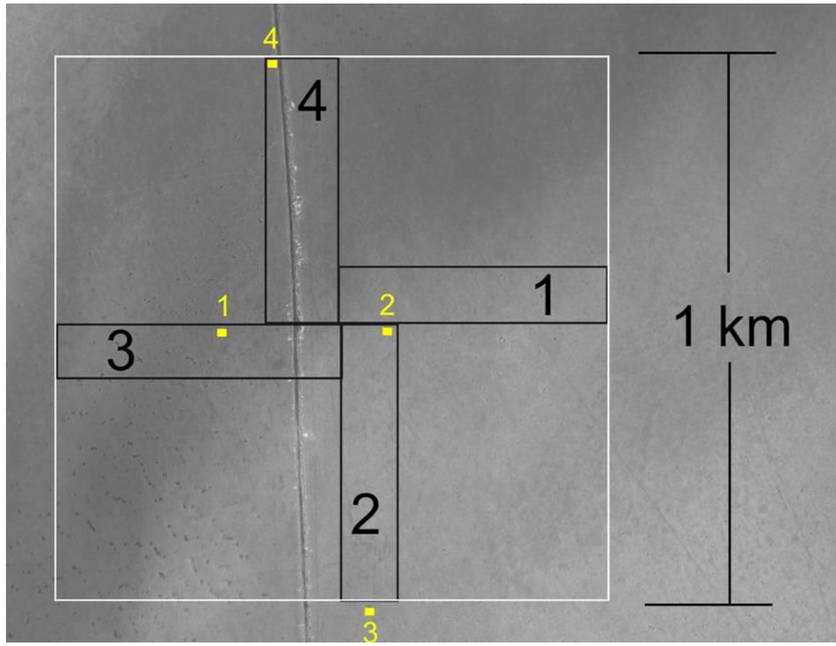
Early JACIE results comparing three different sensors using two different band-averaging approaches

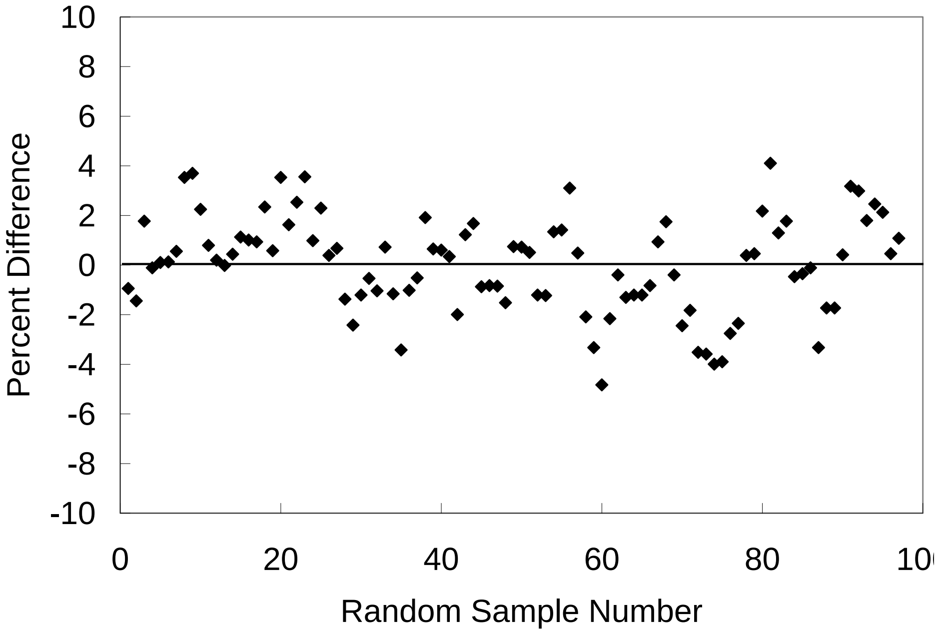


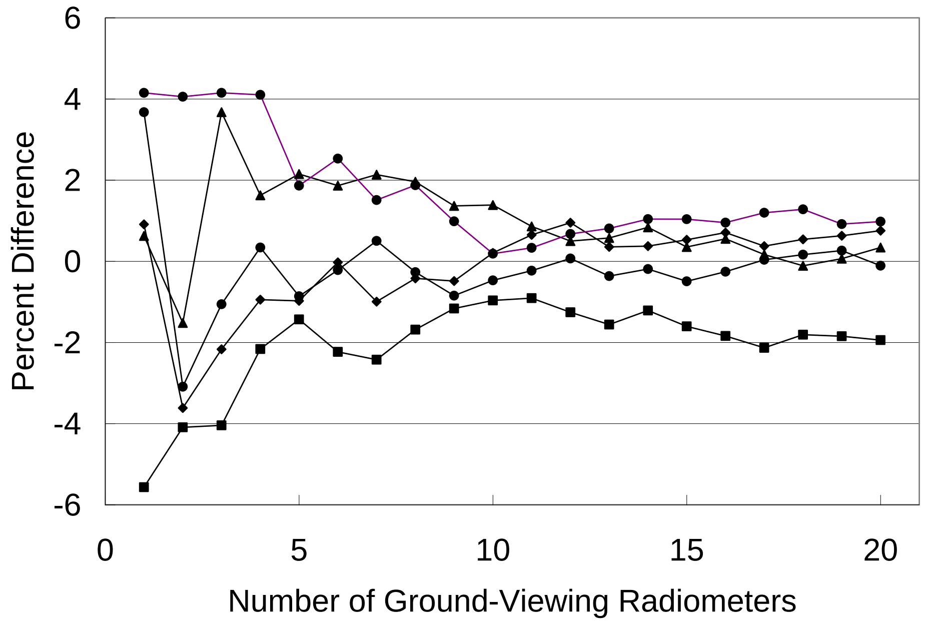
Would low cost sensors work?

Answer is a resounding **yes** but the next question became
What applications are suitable for a given low-cost sensor?

- QuickBird is not Landsat just as Landsat is not MODIS
- QuickBird was not suitable as an intercalibration reference due to swath width, scheduling, and cost
- QuickBird was excellent for evaluating spatial sampling for vicarious calibration sites
- Drone sensors show a similar capability



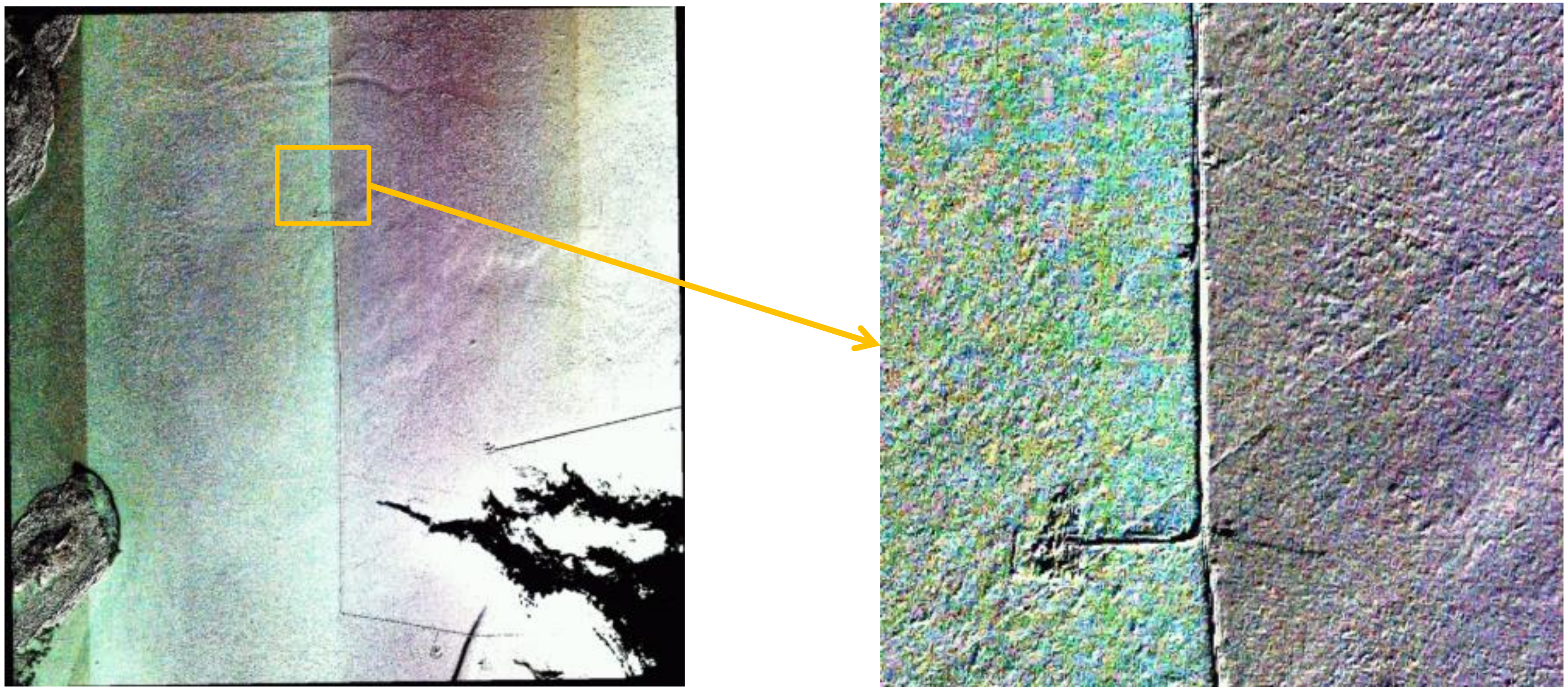




User community is great at finding striping

One of the first lessons learned by this speaker when dealing with scientists using early commercial data

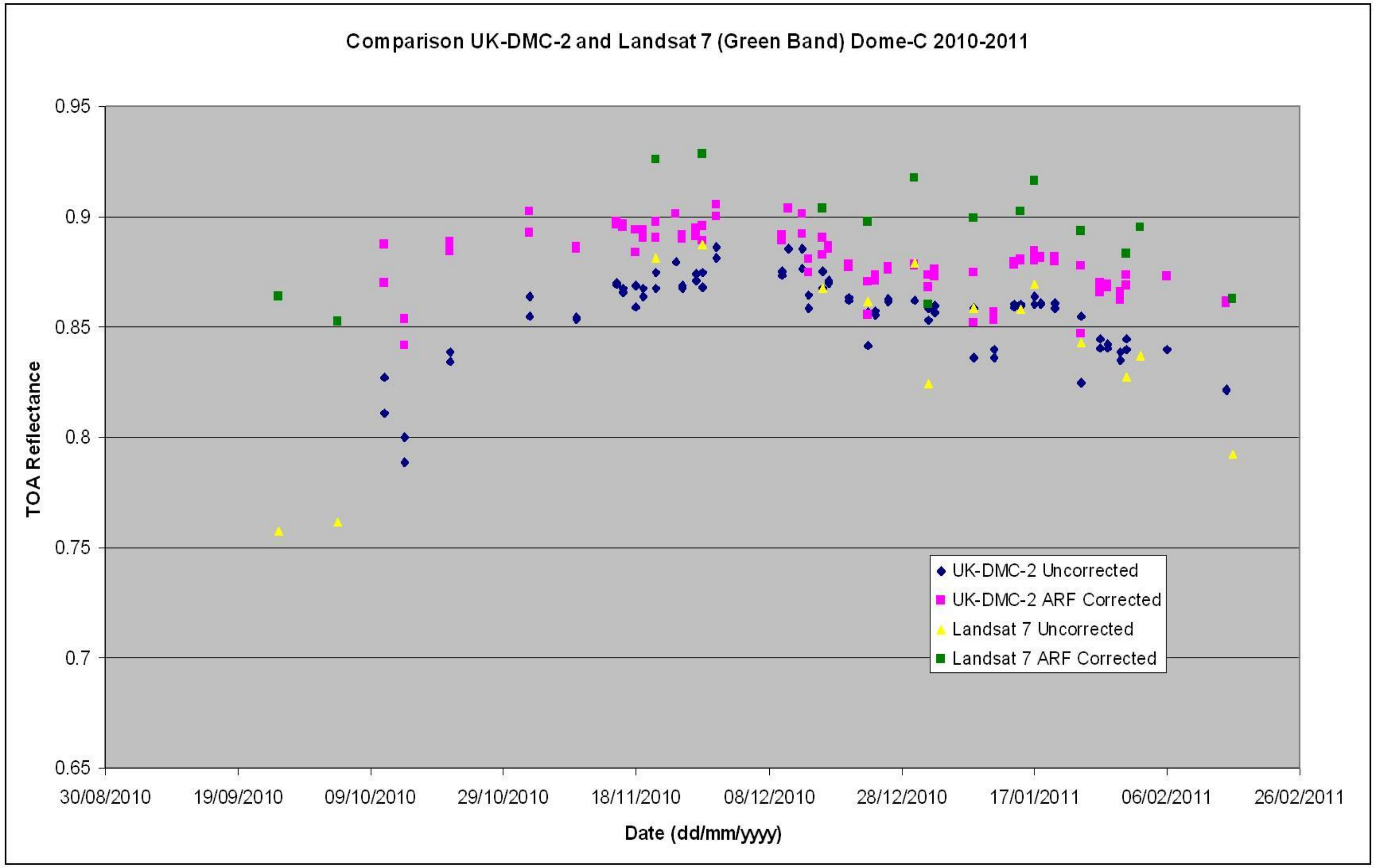
- Still true today
- Scene shown here is a contrast stretch of a snow-covered Railroad Valley scene with 1% variation across the subscene at right



Removing subtle differences was an early goal

Commercial providers developed numerous methods to improve relative calibration

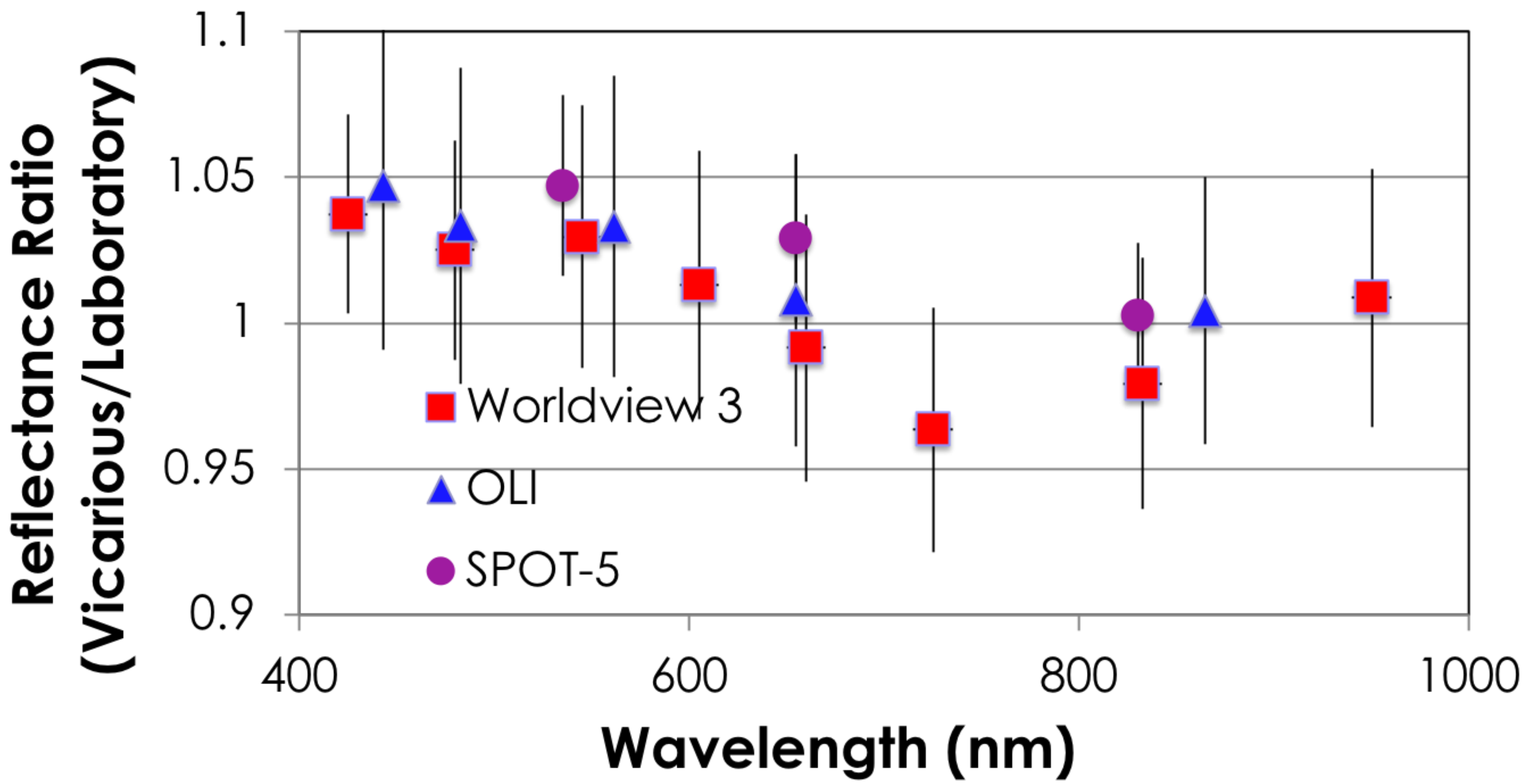
- Cross-sensor methods within their constellations
- Cross-sensor methods with "gold standards"
- Understanding the subtle effects caused by scene and sensor variations



There is a difference between significant and noticeable

All three sensors shown here meet their absolute radiometric uncertainty and are harmonised

- **Users will still see noticeable differences!!!**
- Some differences are physically based
  - Atmospheric absorption effects
  - View geometries
  - Collection times
  - Spatial resolutions

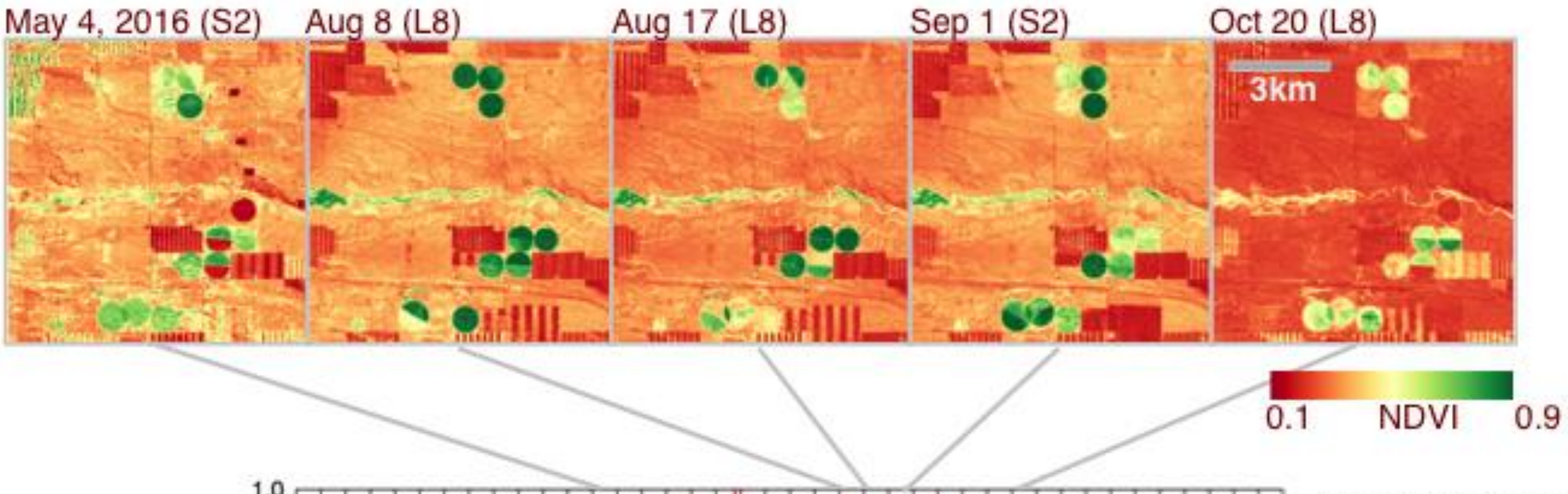


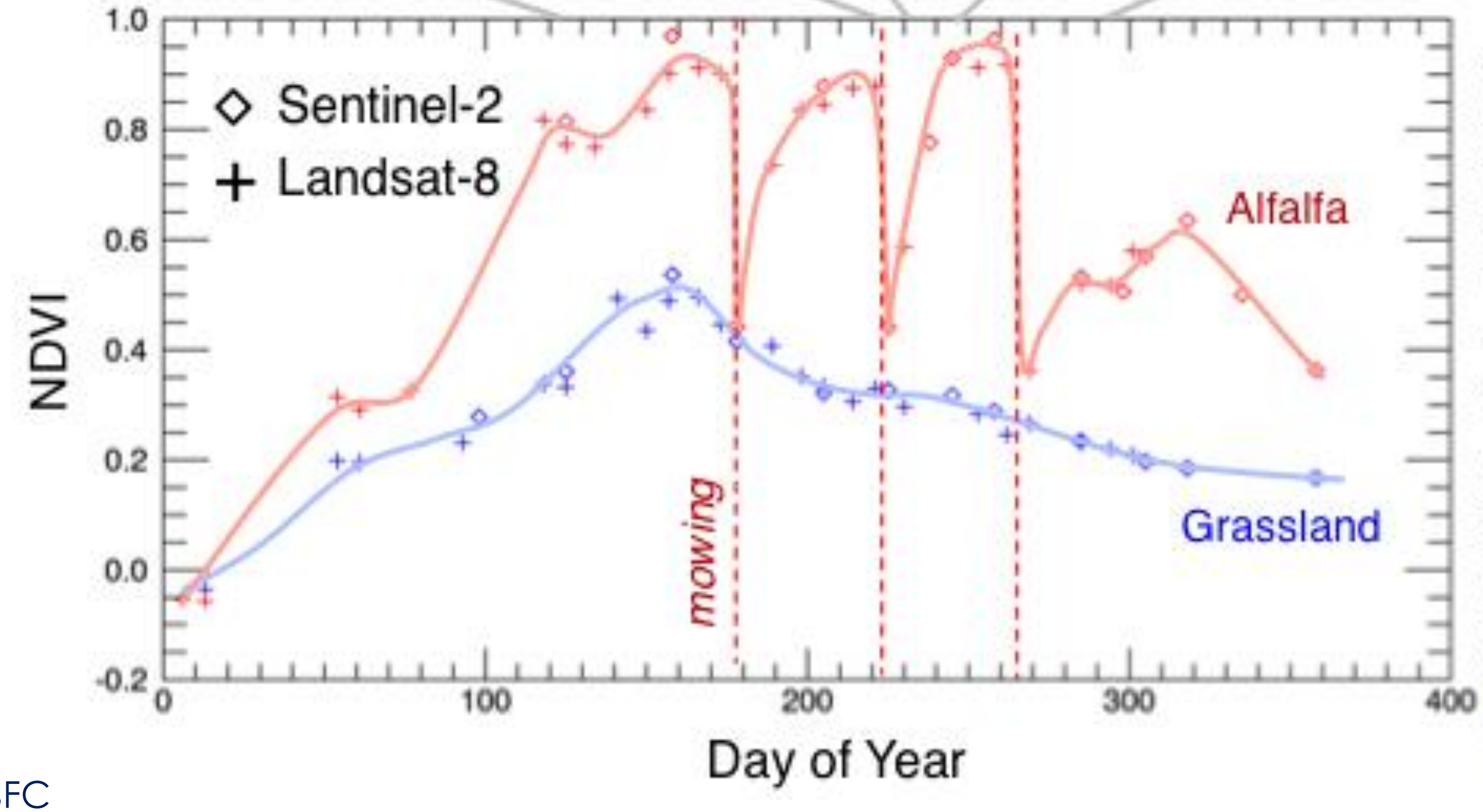
Objective of calibration process is to verify **requirements**

Objective for some users is to **eliminate differences** related to the sensor to obtain seamless comparisons

Multiple sensor, global data products will have noticeable artifacts

Users relying on time series analysis from single sensors as well as combinations of multiple sensors such as Harmonized Landsat / Sentinel-2 Products - Laramie County, WY





Seasonal phenology (greening) for natural grassland (blue line) and irrigated alfalfa fields (red line) near Cheyenne Wyoming observed from Harmonized Landsat/ Sentinel-2 data products. The high temporal density of observations allows individual mowing events to be detected within alfalfa fields. HLS Products available from https://hls.gsfc.nasa.gov

Noise in the plot at right can be due to
- Intercalibration differences
- Residual spectral effects
- BRDF effects
- Residual atmospheric impacts

Jeff Masek, Junchang Ju, Eric Vermote, NASA GSFC
Martin Claverie, Jean-Claude Roger, Sergii Skakun, University of Maryland
Jennifer Dungan, NASA ARC

Conclusions - again

- We should attempt to fight the next battle not the current (or past)
- User needs should define the extent of calibration – but defining the user will still be a challenge
- We will never be able to predict when a sensor will misbehave
  - SI-Traceability with established uncertainty mitigates the impact
  - Critical to ensure that sufficient preflight sensor characterization has taken place (could be viewed as a next battle)
- Cal/Val community needs to continue to advocate for the their users
- It is not possible to produce a global seamless data product from multiple sensors without noticeable artifacts using current approaches
  - User community is great at finding striping
  - Community has to understand the difference between significant and noticeable
- We are way better off than we were in 2010 (let alone 1990) so imagine what it could be like in 2030